5 DYNAMIC FREQUENCY SELECTION IN A WIRELESS
COMMUNICATION NETWORK

This patent is a continuation of pending provisional patent
application entitled Joint Transmit Power Control and

10 Dynamic Frequency Selection For Wireless Local Area
Networks, having a provisional application number of
60/283,848, and a filing date of 4/13/01.

TECHNICAL FIELD OF THE INVENTION
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This invention relates generally to wireless
communication systems and more particularly to frequency,
and/or channel, allocation in such wireless communication
systems.
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BACKGROUND OF THE INVENTION

Wireless communication systems are known to support
wireless communications between wireless communication
25 devices affiliated with the system. Such wireless
communication systems range from national and/or
international cellular telephone systems to point-to-point
in-home wireless networks. Each type of wireless
communication system is constructed, and hence operates, in
30 accordance with one or more standards. Such wireless
communication standards include, but are not limited to
IEEE 802.11, Bluetooth, advanced mobile phone services
(AMPS), digital AMPS, global system for mobile
communications (GSM), code division multiple access (CDMA),
35 wireless application protocols (WAP), local multi-point

distribution services (LMDS), multi-channel multi-point distribution systems (MMDS), and/or variations thereof.

An IEEE 802.11 compliant wireless communication system includes a plurality of wireless communication devices (e.g., laptop, personal computer, personal digital assistant, et cetera) coupled to a station and a plurality of access points. The access points are physically distributed within the wireless communication system to provide seamless wireless services throughout the system for its wireless communication devices. As is known, each access point utilizes one of a plurality of channels (i.e., frequencies) to communicate with affiliated stations, (i.e., stations within the coverage area of the access point and registered with the access point). Such coverage area is generally referred to as a basic service set (BSS). To minimize interference between adjacent BSSs, access points use different channels. The use of differing channels forms a pattern of channel reuse, which is commonly referred to as a cell pattern.

Currently, the establishment of a cell pattern within a wireless communication system is a manual process. As such, when a BSS is added to or deleted from a wireless communication system, the cell pattern is manually revised (i.e., channel assignments are determined by a human system administrator, who reprograms the access points based on their new channel assignments). As with many computational intensive processes, having key decisions made by humans lead to potential errors, requires highly trained personnel, and is expensive.

As is also known, once a cell pattern is established there are few mechanisms to verify that the channel pattern is optimal (i.e. a BSS has acceptable levels of interference from adjacent BSSs). Typically, unacceptable
5   interference is detected when customers (e.g., users of wireless communication devices) complain of poor service quality.

Therefore, a need exists for a method and apparatus
10   that automates an access point's channel selection for optimal cell patterns, automates channel reallocation when interference on a current channel is unacceptable and/or to conform to regulatory requirements.

15   **BRIEF DESCRIPTION OF THE DRAWINGS**

Figure 1 illustrates a schematic block diagram of a wireless communication system in accordance with the present invention;
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Figure 2 illustrates a graphical representation of a cell pattern in accordance with the present invention;

Figure 3 illustrates a frequency spectrum of channels
25   that may be used by the wireless communication system in accordance with the present invention;

Figure 4 illustrates a logic diagram of a method for dynamic frequency selection in a wireless communication
30   system in accordance with the present invention; and

Figures 5 through 7 illustrate logic diagrams that further define steps within the method of Figure 4.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

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Generally, the present invention provides a method and apparatus for dynamic frequency selection in a wireless communication system or network. Such a method and apparatus includes processing that begins when an access

10 point determines interference on a wireless channel that is being used by the access point (i.e., current wireless channel). When the interference exceeds an interference threshold, or at random times determined by the access point, the access point provides a request packet to at

15 least some of the affiliated stations being serviced by the access point for channel spectrum information. The processing continues as the affiliated stations, which receive the request, generate the channel spectrum information regarding each of the wireless channels in the

20 wireless communication network. The processing proceeds then as the affiliated stations provide the channel spectrum information to the access point via the current wireless channel. The access point interprets the channel spectrum information to determine a desired wireless

25 channel of the plurality of wireless channels within the wireless communication network. The interpretation may lead the access point to determine that the current wireless channel is the best channel to use at this time or another channel would provide a higher quality (i.e., less

30 interference). The access point then provides a selection packet to the affiliated stations via the current wireless channel to indicate that the access point will begin using

the desired wireless channel at a particular future time. With such a method and apparatus, an access point may dynamically select the particular channel it will use based on interference from adjacent channels acquired from its

5   affiliated stations, thus optimizing cell pattern channel allocations and enabling an access point to reallocate its channel to improve quality of service.

The present invention can be more fully described with

10   reference to Figures 1 through 7. Figure 1 illustrates a schematic block diagram of a wireless communication network, or system, 10 that includes a plurality of basic service sets 12 and 14 and a network hardware component 16. Each of the basic service sets (BSS) 12 and 14 include an

15   access point 20 and 56 and a plurality of wireless communication devices. Each wireless communication device includes a device operably coupled to a station. For example, basic service set 14 includes device 30 operably coupled to station 22, device 32 operably coupled to

20   station 24 and device 34 operably coupled to station 28. Similarly, basic service set 12 includes device 66 operably coupled to station 58, device 68 operably coupled to station 60, device 70 operably coupled to station 62 and device 72 operably coupled to station 64. As one of

25   average skill in the art will appreciate, devices 30-34 and 66-72 may be a laptop computer, personal computer, server, home entertainment equipment, personal digital assistant, and/or any other device that may transceive wireless data via a station.

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The network hardware 16 couples the wireless communication network to a network connection 18.

Accordingly, the network hardware 16 may be a server, gateway, router, bridge, modem, and/or any device that provides a connection to the Internet, Local Area Network, and/or Wide Area Network. The network connection 18 may be

5   a cable connection, twisted pair connection, fiber optic connection, et cetera.

In operation, any of the devices 30-34 and 66-72, via its associated station 22-28, 58-64, may communicate with

10 any other device in the wireless communication network either directly or via an associated access point or points. In addition, each device, via its station, may communicate via the network connection 18 to provide interconnection to the World Wide Web, email, et cetera.

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To facilitate communications and to support the dynamic frequency selection described herein, each access point 20 and 56 includes an antenna switch 44, receiver 40, transmitter 42, access point processing module 36 and

20 access point memory 38. The access point processing module 36 may be a single processing device or a plurality of processing devices. Such a processing device may be a microprocessor, microcontroller, microcomputer, digital signal processor, field programmable gate array,

25 programmable logic device, state machine, logic circuitry, analog circuitry, digital circuitry, and/or any device that manipulates signals (analog and/or digital) based on operational instructions. The access point memory 38 may be a single memory device or a plurality of memory devices.

30 Such a memory device may be read-only memory, random access memory, volatile memory, non-volatile memory, static memory, dynamic memory, flash memory, and/or any device

that stores digital information. Note that when the
processing module 36 implements one or more of its
functions via a state machine, logic circuitry, analog
circuitry and/or digital circuitry, the memory storing the
5   corresponding operational instructions is embedded within
the circuitry comprising the state machine, logic
circuitry, analog circuitry and/or digital circuitry. The
operational instructions stored in memory 38 and executed
by processing module 36 are graphically described with
10   reference to this figure, Figures 2 through 3 and in logic
diagrams 4 through 7.

The basic service set 14, or 12, supports, via the
associated access point 20 or 56, a single wireless channel
15   of a plurality of channels used within the wireless
communication network 10. To obtain access to the wireless
communication channel, the stations of the basic service
set utilize a carrier sense multiple access with collision
detection or avoidance scheme. Accordingly, there will be
20   times when the channel is not in use. When the channel is
idle, the access point 20 may determine interference on the
channel from adjacent basic service sets, for example,
basic service set 12. The access point 20 measures the
interference 25 and determines whether it exceeds an
25   interference threshold. For example, the access point 20
will determine the receive signal strength of the
interference channel 25.

If the receive signal strength is unfavorable with
30   respect to a desired threshold, which may be based on a
signal to interference ratio, signal to noise ratio (e.g.,
less than 10 dB difference), frame failures (i.e., too many

transmitted frames are not acknowledged), etc., the access point determines that the interference 25 has exceeded the threshold. When this is the case, the access point 20

5 generates a packet that requests each affiliate station to determine the signal energy on at least some of the plurality of channels supported by the system. The access point 20 transmits the request via the channel it is currently using to communication with its affiliated stations.

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As an alternative to, or in addition to, determining undesirable interference on the current channel, the access point 20 may randomly provide a request for channel spectrum information to at least some of the affiliated

15 stations. In this instance, the access point can accumulate channel spectrum data during idle times of the system, at periodic intervals, and/or any other metrics regarding system operation.

20 As a further alterative, and/or addition to, providing the request, the access point may specify the level of channel spectrum information is to be collected by the stations. For example, at one level, the request may request the receiving stations to provide power level

25 indications of a set of specified channels, which may be some or all of the plurality of channels supported by the system. At another level, the request may request the stations to identify use of channels and provide the identification code of the access point using the

30 particular channel. Such specific channel use information may be requested alternatively, or in addition to, providing the interference level information. Further, the

access point may request differing levels of information from different stations.

In response to the request, a station determines the received signal strength indication (RSSI) for at least some of the channel in the wireless communication system. Since each station may be located anywhere within the coverage area of the basic service set, the received signal strength indications for a given channel will differ from the station to station. Note that the request provided by the access point may indicate which channels to determine RSSI, the station may determine which channels to determine RSSI, or a combination thereof.

The access point accumulates the channel spectrum information from the stations and determines whether an alternate channel will provide a higher quality of service (i.e., has a lower RSSI for interfering channels, has a better signal to interference ratio, a better signal to noise ratio, less frame failures, etc.). If this is the case, the access point 20 generates a packet indicating to the stations within its basic service set that it will switch to a different channel and when the switch will occur.

Each station, as depicted by station 22, includes an antenna switch 54, receiver 50, transmitter 52, station (STA) memory 48 and station (STA) processing module 46. The STA processing module 46 may be a single processing device or a plurality of processing devices. Such a processing device may be a microprocessor, microcontroller, microcomputer, digital signal processor, field programmable

gate array, programmable logic device, state machine, logic
circuitry, analog circuitry, digital circuitry, and/or any
device that manipulates signals (analog and/or digital)
based on operational instructions. The STA memory 48 may

5   be a single memory device or a plurality of memory devices.
Such a memory device may be read-only memory, random access
memory, volatile memory, non-volatile memory, static
memory, dynamic memory, flash memory, and/or any device
that stores digital information. Note that when the

10   processing module 36 implements one or more of its
functions via a state machine, logic circuitry, analog
circuitry and/or digital circuitry, the memory storing the
corresponding operational instructions is embedded within
the circuitry comprising the state machine, logic

15   circuitry, analog circuitry and/or digital circuitry. The
memory 48 stores and STA processing module 46 executes at
least some operational instructions that are graphically
described with reference to this figure, Figures 2 and 3
and in logic diagrams 4 through 7.

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The receiver 50 includes an RSSI determination module
to measure the received signal strength of each of the
channels in the wireless communication system when
requested by the access point, or other type of error

25   detection circuitry including Signal to Noise ratio, Signal
to Interference ratio, packet failures, etc. The
processing module 46 accumulates this information and
provides it as channel spectrum information back to the
access point.

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Figure 2 illustrates a graphical representation of a
cell pattern for three basic service sets. In this

illustration, one access point (AP), for example AP-X, utilizes a 1st channel of the channels available within the wireless communication section system, a 2nd access point, for example AP-Y, uses a 2nd channel and a 3rd access point,

5   for example AP-Z, uses a 3rd channel. The illustration includes multiple stations (A through K) that are affiliated with one of the access points. The affiliation, which is represented by a solid line, indicates that the station is registered with the corresponding access point.

10 The dashed line indicates interference that an AP may receive from a station that is registered with an adjacent AP. For example, station A is affiliated with access point X and may provide interference, when transmitting, to access point Y. Similarly, station B is affiliated with

15 access point Z and may provide interference, when transmitting, to access point X.

If access points X, Y, and Z are using adjacent channels, for example, channels 1, 2 and 3, respectively,

20 as depicted in Figure 3, a certain level of adjacent channel interference will be produced by the stations within overlapping coverage areas to the non-affiliated access point. For instance, if access point X utilizes channel 1, access point Y utilizes channel 2, and access

25 point Z utilizes channel 3 when station A is transmitting, access point Y will receive, to some degree, adjacent channel interference of channel 1 due to station's A transmission. If this interference is substantial, i.e., has a received signal strength indication that degrades the

30 performance of transmitting and receiving data on channel 2, access point Y will begin the dynamic frequency selection process. Alternatively, access point Y may

periodically initiate the dynamic frequency selection process without cause. After performing the dynamic channel selection process, if access point Y determines that, for example, channel 5 is available and has a lower

5   of interference, access point Y will switch its channel of use from channel 2 to channel 5.

Each access point in the wireless communication network may perform the dynamic frequency or channel

10 selection process either based on a determination that its current channel has too much interference or whenever it so chooses. As such, when a basic service set is added or deleted from the network, the access points may adjust and/or reallocate its channel assignment to reduce adjacent

15 channel interferences. In addition, whenever an access point determines that its current channel is not optimal (i.e., more interference than desired), the access point may initiate the dynamic frequency selection process.

20   In general, the dynamic frequency selection process, when initiated by an access point, requests at least some of the stations affiliated therewith to determine the receive signal strength of at least some of the channels within the wireless communication network. For example, if

25 access point Y initiates the dynamic frequency selection process, it sends a packet to stations A, C, F and/or E on the currently allocated channel requesting that each station receiving the request determines the receive signal strength of the identified channels within the wireless

30 communication network and/or to determine which access points are using which channels. If the plurality of channels used by the wireless communication system is as

shown in Figure 3, each station receiving the request will determine a receive signal strength for channel 1 through channel n, or a subset thereof as identified within the request, as determined by the station, or as determined by

5 a default setting. Accordingly, based on its position within the coverage area of access point Y and the coverage areas of adjacent access points, the receive signal strength for each channel will vary from station to station. For example, if access point X is using channel

10 1, the receive signal strength indication obtained by station A will be larger than the receive signal strength indication obtained by station E. Based on the receive signal strength indication of the channels, and/or channel use information, provided by the stations, the access

15 point, for example access point Y, may determine a new channel to utilize or may determine that the current channel is the best available.

Figures 4 through 7 illustrate a logic diagram of a

20 method for dynamic frequency selection in a wireless communication network. The process begins at Step 80 or at Step 86. At step 80, an access point determines interference on a current wireless channel of a plurality of wireless channels. The current wireless channel is the

25 channel that the access point is utilizing to communicate with affiliated stations within its coverage area. The determination of the interference may be done by transmitting a holding packet on the current wireless channel, wherein the holding packet addresses an invalid

30 station. Accordingly, no station will reply. Thus, the access point may measure the interference on the current wireless channel during a transmit period allocated to the

invalid station. A further discussion of the determination of the interference will be described in greater detail with reference to Figure 7.

5   The process then proceeds to Step 82 where the access point determines whether the interference on the current wireless channel exceeds an interference threshold. Such interference may be caused by another BSS utilizing the same frequency or a strong interference source of any kind.

10   Significant interference (i.e., exceeding the threshold) may also be indicated if the access point sees a low acknowledgment rate with respect to its packet transmitted to its affiliated stations. For example, the access point may determine that the interference on the current wireless

15   channel is too large when the signal-to-noise ratio is 10 dB or less. Alternatively, the access point may determine that less than 95% of its transmitted packets are being acknowledged. If the interference does not exceed the threshold, the process proceeds to Step 84 where the access

20   point continues to use the current channel.

       If, however, the interference exceeds the threshold, or the access point is randomly accumulating channel spectrum data, the process proceeds to Step 86. At Step

25   86, the access point provides a request packet that request channel spectrum information to at least some affiliated stations via the current wireless communication channel. The request for channel spectrum information may be at various levels. For instance, at one level the channel

30   spectrum information may include RSSI for each channel used by the system, RSSI for some of the channels used by the system, use information (e.g., identify the access point

using a particular channel) for each of the channels used
by the system, use information for some of the channels
used by the system, or a combination thereof.

5   As previously mentioned, an affiliated station is one
that is within the coverage area of the access point and is
registered with the access point. The providing of the
request packet to the affiliated stations may be done by
polling the stations, enabling the stations to periodically
10   generate the channel spectrum information and/or enabling
the affiliated stations to spontaneously generate the
channel spectrum information. For example, if the polling
process is to be used, the access point sends a frame
containing the request message to the stations. This frame
15   may be in the form of a probe request frame with a dynamic
frequency response request element.

The process then proceeds to Step 88 where the
affiliated station generates the channel spectrum
20   information of the plurality of wireless channels. This
will be described in greater detail with reference to
Figure 5. The process then proceeds to Step 90 where the
3rd station provides the channel spectrum information to the
access point via the current wireless channel. The
25   providing of the channel spectrum information may be done
in a response element as illustrated in the following
tables.

Table 1: Response Element - Top Level

Octets:1	1	1	1	8	8	1	Variable
Element ID	Length	Channel	Time Interval	Total RSSI Histogram	Unknown RSSI Histogram	Number of BSSID Sets	BSS Sets

The Channel and Time Interval octets are the same
information that was received in the Response element of
the Probe Request frame. The Total RSSI histogram
describes the RSSI levels seen over the time interval. The
format for the Total RSSI information is as shown in Table
2.

Table 2: Total RSSI Histogram Octets

Octet:1	1	1	1	1	1	1	1
RSSI 0 Time	RSSI 1 Time	RSSI 2 Time	RSSI 3 Time	RSSI 4 Time	RSSI 5 Time	RSSI 6 Time	RSSI 7 Time

Each octet contains the amount of observation time in
time units (TU's) that the receiver measured the particular
RSSI level. Any observation that is greater than zero, but
less than 1 TU is rounded up to 1 TU.

The Unknown RSSI Histogram describes the signals that
are received with valid PLCP headers, but for which the MAC
header information connate be reliably determined. It has
the form as shown in Table 3.

Table 3: Unknown RSSI Histogram Octets

Octet:1	1	1	1	1	1	1	1
RSSI 0 Time	RSSI 1 Time	RSSI 2 Time	RSSI 3 Time	RSSI 4 Time	RSSI 5 Time	RSSI 6 Time	RSSI 7 Time

Each octet contains the amount of observation time in
TU's that the receiver measured the particular RSSI level
on signals with valid PLCP headers, but for which the MAC
header information could not be reliably determined. Any

observation that is greater than zero, but less than 1 TU is rounded up to 1 TU.

After the Unknown Histogram is the Number of BSSID
5 Sets octet followed by the BSS Sets. A maximum of four BSS Sets may be included in each Response Element. Each BSS Set has a variable length that is determined by the number of stations that were observed on the channel. The format of the BSS Sets is shown in Table 4.

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Table 4: BSS Sets

Octet:6	2	2	3-10	6
BSSID	Beacon Interval	Capability Information	Supported Rates	CF Parameter Set

Octet: 4	1	Variable
IBSS Parameter Set	No. of Station Sets	Station Sets

The Beacon Interval, Capability Information, Support
15 Rates, CF Parameter Set, and IBSS Parameter Set are taken from the elements of a beacon frame from the AP in the BSS. The Number of Station Sets octet is the number of Station Sets that are reported in the response. The format of each Station Set is given in the Table 5.

20

Table 5: Station Sets

Octets: 6	16
Station Address	RSSI Histogram

Each Station Set has the Station Address and an RSSI Histogram that describes the signal level distribution of
25 the frame from the station. The histogram element is as shown in Table 6.

Table 6: RSSI Histogram Octets

Octet:1	1	1	1	1	1	1	1
RSSI 0 Time	RSSI 1 Time	RSSI 2 Time	RSSI 3 Time	RSSI 4 Time	RSSI 5 Time	RSSI 6 Time	RSSI 7 Time

Each octet contains the total amount of time (in TU's)
that frames were received from the particular station at
the particular RSSI level.

Returning to the main flow, the process then proceeds
to Step 92 where the access point interprets the channel
spectrum information to determine a desired wireless
channel of the plurality of channels. This will be
described in greater detail with reference to Figure 6.
Note that the access point may also choose the desired
wireless channel based on a priority. For example, for an
802.11a application, the channels may be grouped into three
groups: the 1st group including channels within the
frequency range of 5.15 gigahertz to 5.25 gigahertz, the 2nd
group containing the four channels in the frequency range
of 5.25 gigahertz to 5.35 gigahertz and the 3rd group
containing four channels in the 5.725 to 5.825 gigahertz
range. Such a prioritization scheme would first have the
access point choose another channel within the same group
if such a channel is available. If not, the access point
would choose a channel in the closer group when switching
to that group. Finally, if neither of those options is
available, the access point chooses the farthest channel
from the current channel to avoid any possible residual
interference.

The process then proceeds to Step 94 where the access
point provides a selection packet to the affiliated station
via the current wireless channel to change to the desired
wireless channel at a future time. Note that the access

5   point, in combination with other access points are
generating a basic service set pattern with its neighboring
access points based on the channel spectrum information
received by each access point. Thus, the access points are
optimizing the cell pattern for the wireless communication

10   network.

Figure 5 illustrates a logic diagram that further
describes the generating of the channel spectrum
information by an affiliated station. The process begins

15   at Step 96 where the affiliated station tunes to the
frequency of at least some of the wireless channel channels
in the system as identified in the request or as otherwise
identified. The process then proceeds to Step 98 where the
affiliated station measures the interference on each

20   wireless channel to produce channel interference data. The
process then proceeds to Step 100 where the affiliated
station compiles the channel interference data for each
wireless channel to produce the channel spectrum
information. Note that the interference may be determined

25   by determining the outage RSSI level for each channel.

Figure 6 illustrates a logic diagram that further
describes the interpreting the channel spectrum data by the
access point. The process begins at Step 102 where the

30   access point computes an outage receive signal strength
indication level. The process then proceeds to Step 104
where the access point compares the outage receive signal

strength indication level with a targeted receive signal
strength indication level. The process then proceeds to
Step 107 where the access point determines that another
wireless channel needs to be selected when the outage RSSI
5   level compares unfavorably with the targeted outage RSSI
level. Accordingly, the access point may select another
channel when it has a more desirable RSSI level with
respect to the target outage RSSI level. Alternatively,
the access point may determine that it is best to stay with
10   the current wireless channel based on the RSSI information.

Figure 7 illustrates a logic diagram that further
describes the determining that the interference exceeds the
interference threshold. The process begins at Step 108
15   where the access point determines that the interference on
the current wireless channel exceeds a 1st interference
threshold. Accordingly, the access point determines that
the receive signal strength indication and/or signal-to-
noise ratio of incoming signals on the current wireless
20   channel are above a selected threshold (e.g., 10 dB). The
process then proceeds to Step 110 where the access point
provides an increase power packet to the affiliated
stations, which request that the affiliated stations
increase their transmit power levels. The process then
25   proceeds to Step 112 where the access point determines the
interference on the current channel with the affiliated
stations transmitting at the higher power level. If the
interference is still above the 1st threshold, the process
proceeds to Step 114 where the access point generates the
30   request packet.

The preceding discussion has presented a method and apparatus for dynamically selecting frequencies and/or channels in a wireless communication network. By compiling interference levels received by each station affiliated

5   within an access point, the access point can readily determine which channel will best serve its stations. Accordingly, the access point may change its channel of use to improve the quality of service and minimize the interference from adjacent basic service sets. As one of

10 average skill in the art will appreciate, other embodiments may be derived from the teachings of the present invention, without deviating from the scope of the claims.